Designing a Virtual Keyboard with Multi-Modal Access for People with Disabilities

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Abstract—**Virtual keyboards or on-screen keyboards are commonly used as a means of augmentative communication by people with severe speech and motion disability. Any such virtual keyboard is characterized by keys' layout design and method of access. In this paper we present a virtual keyboard that can support multiple modes of access and has an optimum layout based on the frequency of occurrence of alphabet in English text. We have compared our proposed layout against commonly used alphabetical layout, which demonstrates a superior performance of our design.**

Keywords - Augmentative communication, virtual keyboards, scanning and access switches, brain-computer interfacing, eye tracking.

I. INTRODUCTION

People suffering from speech and motor disorders face problems in expressing themselves in an easy and intelligible way, which significantly reduces their ability to interact with the outside world. Consequently they rely on external aids such as computer based augmentative and assistive communication (AAC) systems to perform their day to day communication [1]. A virtual keyboard (VK) also referred to as soft or on-screen keyboard is used as an input interface for such computer based AAC systems. The keys of a VK are laid spatially on the computer screen. Users compose text making single letter selections. Selection of keys from a VK poses a significant problem for users with severe motor disability as they cannot use standard input devices like mouse. Scanning and access switches [2] requiring lesser motor control are commonly used. Brain-computer interface (BCI) which translates the intent of a subject measured from brain signals directly into control command [3] and eye tracking [4] which uses fixed gaze or blinking to activate the switch or triggers are also being used lately.

For operating a VK using access switches or BCI, scanning is used. Scanning is the successive and periodic highlighting of on-screen elements [5]. When the highlighter or focus reaches the desired element, the user activates the switch to select that particular element. In case of a twin button or a three state switch, the user also controls the duration of highlighting while in case of two state switch or simply access switch, during scanning, the highlighter pauses at each element for a fixed duration of time called as the scan period.

For a user of a VK, the performance depends on both the interface layout and the method of access (input) used. A wide variation is possible in both of these, leading to several possible designs. Arnott [6] provides a concise background in efficient text entry methods for AAC communication. Lesher et al. [7] describe a method to automatically interpret each keystroke using statistical disambiguation algorithms. Bhattacharya et al. [8] provide performance models for automatic evaluation of virtual keyboards. Dasher system [9] is a predictive text entry interface driven by continuously pointing gestures. It can be operated with various input devices such as eye-trackers, joysticks and touch-screens appropriate for users with special needs. An efficient mental Hex-O-Spell VK interfaced to an EEG based BCI with two mental states is reported in [10]. Herein, there are six hexagonal fields which surround a circle. Six different selection/choices are arranged in each of these hexagons. For the selection of an alphabet/symbol, there is an arrow in the centre of the circle. Imagining a right hand movement turns the arrow clockwise; and imagining foot movement stops the rotation and extends the arrow. If this imagination is performed over a longer period of time, the arrow touches the hexagon and thereby selects it. Inspired by the Hex-O-Spell [10], the VK design presented in this paper facilitates multi-modal access and outlines a simple method for optimal character placement and an experimental approach for obtaining appropriate scan time.

This paper is organized as follows. Section II of the paper introduces the proposed virtual keyboard explaining its working, modes of access and layout design in detail. Analysis and testing of the VK is presented in Section III. Results and discussion are in Section IV. The conclusions and further works are outlined in Section V.

II. POPOSED VIRTUAL KEYBOARD

A. *The Working of the VK*

Fig. 1 (a) and (b) show the graphical user interface (GUI) of the proposed VK developed in Visual Studios 2008. It consists of eight sub circles contained in a larger circle and an arrow that rotates in clockwise direction. Each sub circle consists of a group of keys representing alphabets, numbers, punctuation, navigation keys and other keyboard keys. There is a side bar that lists all the predicted words. They can be accessed using the prediction sub circle. The arrow can be rotated either by the user or can be set to rotate automatically and will highlight each sub circle or element for a fixed scan period set by the user. Initially the arrow points vertically to the first sub circle. The user can compose the text in the following manner.

- The pointer is rotated till the desired sub circle is highlighted and the user then triggers the access switch (Fig. 1(a)).
- The sub circle expands and again the arrow is rotated till the desired element is highlighted when the user again triggers the access switch, the desired key is selected. In case, the user has selected the wrong sub circle s/he can use the 'Go Back' element to return to the main menu (Fig. 1(b)).
- Once the selection has been made, again the arrow starts from the first sub-circle.

Thus by selecting one element at a time in both circles the user composes the desired text.

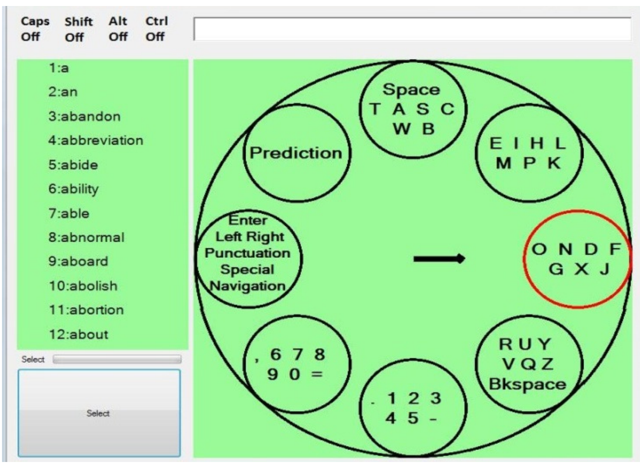

Fig. 1(a): Virtual Keyboard: pointer pointing at the sub circle.

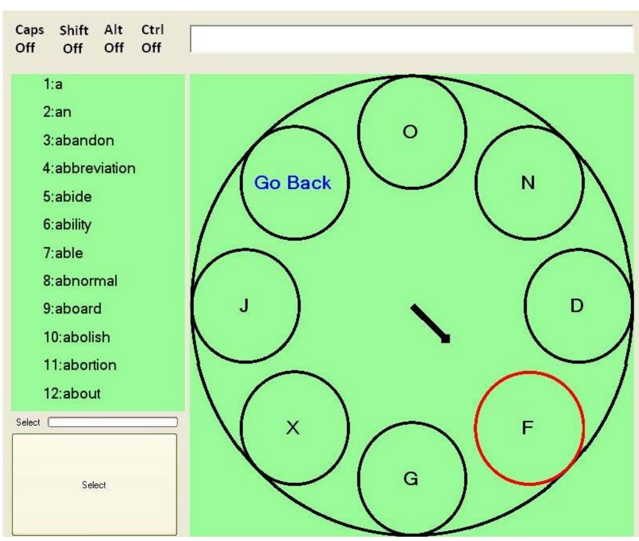

Fig. 1(b) Expanded Sub Circle: pointer points at the character F

B. *Modes of input accesss*

Since each user has different levels of impairments, requiring different modes of access, it was realized that multiple modes of access must be supported. Hence we incorporated three different modes of access in the same VK. Also, depending on the severity of impairments, the user can either rotate the arrow by her/himself if s/he has twin button switch or can set it to rotate automatically for a fixed scan period. The following three input methods have been incorporated which can be used independently or in combination.

- The BCI access switch translates brain signals into control command based on EEG recordings. It uses vivid imagination of right hand motion and left hand motion as the two states of the switch. It was developed in MATLAB Simulink and incorporated within the main VK application on the client server model.
- The eye tracker technology 'ViewPoint Eye Tracker®' manufactured and marketed by the Arrington Research [4] was used. The eye tracker can be used in one of the following ways. It can be used to gaze at the desired element/ sub-circle which gets highlighted. Either eye blink, or fixed gaze for a set duration can be used to trigger the access switch. In case the user head is not very stationary, we use the rotating arrow to highlight elements and then the blink of eyes to trigger the access.
- A soft switch, enclosed in foam and covered with a removable, washable red bag [2], has also been incorporated. Any USB soft switch can be used to trigger the access. Different types of soft switches which use any active body part such as hand, foot, mouth, head etc. can be used.

C. *The Layout Design*

The VK layout should be such that it facilitates typing fast and error free. Though error rate may vary according to the expertise of the user, the typing rate is heavily dependent on the layout of the keyboard. In case of the VK, which is operated by a soft switch, a BCI, or an eye tracker, it is especially important that the average number of 'activity' such as pressing the soft switch, thinking or gaze fixation to select a character should be minimum. Most common approach is the alphabetical ordering, which doesn't take into account the frequency of usage of each of the alphabets, resulting in high average number of 'activity' per character selection. Here we propose a layout which takes into account factors like frequency of usage and probability of a letter being the first letter in a word. Table I shows the statistical data on the frequency of usage of an alphabet in text [11],[12] and Table II shows the probability of alphabet being the first letter in a word [13]. In English, the *space* is slightly more frequent than the top letter (7% more frequent than, or 107% as frequent as *e*), and the non-alphabetic characters (digits, punctuation, etc.) occupy the fourth position, between *t* and *a*.

Each key position in the VK is organised so as to require a minimum amount of activity. The position 1 in the sub-circle 1(this position henceforth will be referred as (1, 1)) requires 2 select activities only. The position (1, 2) will require 1 select, 1 rotate, and 1 select activities, i.e. a total of 3 activities. The rotate activity is needed in case a person is not using an eye tracker where s/he can directly gaze at the sub-circle or element and also when the user has not set the arrow in auto rotate mode.

The following steps were followed to assign positions to characters:

- For each position in the VK the number of 'activity' required is calculated and they are arranged in increasing order.
- Then each character is assigned a position based on the probability of usage in text, e.g. space being most frequent is assigned position (1, 1) which requires the least activity, only 2.
- We found that a group of characters requires same amount of activities which gives an alternative to change their sub-circles, e.g. 'e' and 't' require 3 activities with two possible positions (1, 2) and (2,1). Now to decide which character gets which sub-circle we use the statistical data of relative frequency of being the first letter of word. The alphabet which is more probable of being the first letter of word is given preference and is assigned the lower sub-circle. Hence, 't' occupies the position (1, 2) while 'e' gets (2, 1).

The Table III shows the position of each of the characters along with the total activities required to select that character. The last column shows the position if the alphabetical ordering is used.

TABLE I. RELATIVE FREQUENCY OF THE ALPHABETS IN ENGLISH TEXT

Character	Frequency	Character	Freqency
A	8.167%	N	6.749%
B	1.492%	O	7.507%
C	2.782%	P	1.929%
D	4.253%	Q	0.095%
E	12.702%	R	5.987%
F	2.228%	S	6.327%
G	2.015%	T	9.056%
H	6.094%	U	2.758%
I	6.966%	V	0.978%
J	0.153%	W	2.360%
K	0.772%	X	0.150%
L	4.025%	Y	1.974%
M	2.406%	Z	0.074%

TABLE II. RELATIVE FREQUENCIES OF THE FIRST LETTERS OF A WORD IN THE ENGLISH LANGUAGE

Character	Frequency	Character	Frequency
A	11.602%	N	2.365%
B	4.702%	O	6.264%
C	3.511%	P	2.545%
D	2.670%	Q	0.173%
E	2.000%	R	1.653%
F	3.779%	S	7.755%
G	1.950%	T	16.671%
H	7.232%	U	1.487%
I	6.286%	V	0.619%
J	0.631%	W	6.661%
K	0.690%	X	0.005%
L	2.705%	Y	1.620%
M	4.374%	Z	0.050%

TABLE III. POSITION OF ALPHABETS IN THE VK BASED ON PROPOSED LAYOUT AND ALSO BASED ON ALPHABETICAL ORDERING.

Position	Activities Required	Proposed Layout	Alphabetically Ordered Layout
1,1	2	SPACE	A
1,2	3	T	B
1,3	4	A	C
1,4	5	S	D
1,5	6	C	E
1,6	7	W	F
1,7	8	B	G
2,1	3	E	H
2,2	4	I	I
2,3	5	H	J
2,4	6	L	K
2,5	7	M	L
2,6	8	P	M
2,7	9	K	N
3,1	4	O	O
3,2	5	N	P
3,3	6	D	Q
3,4	7	F	R
3,5	8	G	S
3,6	9	X	T
3,7	10	J	U
4,1	5	R	V
4,2	6	U	W
4,3	7	Y	X
4,4	8	V	Y
4,5	9	Q	Z
4,6	10	Z	SPACE
4,7	11	BACKSPACE	BACKSPACE

III. EVALUATION AND TESTING

A. *Evaluation of the layout design*

Given a random variable *x*, with the probability of occurrence *p(x),* the expected (mean) value of *x* is given by

$$E(x) = \Sigma_i x_i p(x_i) \qquad (1)$$

where *E(x)* is the expected value of *x* [14].

If *x* denotes the 'total activity' associated with a character (including space) and *p(x)* be the probability of the occurrence of the character in the text based on their relative frequencies, the mean amount of activity required for a character can be computed using (1).

In case of alphabetical layout, the expected amount of activity required is computed to be **6.47.** For the proposed layout, the same activity drops down **4.55.**

This analysis hence shows that the proposed layout fares much better than the alphabetical ordering as the mean (expected) activity required almost drops by 2, meaning much lesser activities are required to type a character using this layout.

B. *User Trials*

For the purpose of testing the performance of the proposed layout and to determine the most appropriate scan period, user trials were carried out under ethical approval from an appropriate authority. Although the VK was designed for persons with disabilities who require assistive communication techniques to help them meet their communication needs, the initial trials were conducted on 7 healthy subjects (5 male and 2 female). Before going into the testing methodology, we outline below various types of errors that we generally come across while operating the VK.

1) *Types of Errors :*

- *Wrong Character Selection (WCS):* This error occurs when a user types a wrong character. Hence the user needs to use backspace to remove the incorrect character and then type in the correct character. This error is the most expensive type of error as it requires the user to go to Backspace which requires both rotation and selection activities and then go to correct character.
- *Wrong Sub Circle Selection (WSCS):* This error occurs when a user, by mistake, selects the wrong sub-circle. Hence the user needs to use the 'Go Back' option provided in the sub circle. This is less expensive than the previous error because there is no need to use the backspace. The user can simply select the correct sub circle when s/he goes back.
- *Failed Selection (FS):* This error occurs when the user realizes that the pointer (arrow) has already moved beyond the correct sub circle when s/he is in main circle or beyond the correct character if in s/he is inside the sub-circle. The user then has to rotate the arrow back to the correct circle/character in non-auto rotate mode or has to simply wait till the arrow completes the full circle and returns back to the correct sub-circle/character in auto-rotate mode.

2) *Testing Methodology*

The following methodology was adopted for the user trial:

- The subjects were given the layout design in advance in print so that they can study it.
- They were explained the working of the VK and were given sometime before the start of the test to familiarize themselves with the VK.
- They were given just one sentence to type using the soft switch under computer controlled rotation (or auto-rotate mode) at four different scan periods 2100ms, 1800ms, 1500ms and 1200ms. The sentence was given to them in print at the time of testing and not before hand.
- They were given a gap of 5-10 minutes between two typing sessions.
- They were just given a soft switch to be used for pressing the select button as the pointer rotated and no prediction help was allowed. No other input device was allowed.
- Only error free words and sentences with full-stops were considered for evaluation i.e. if user typed a wrong letter s/he needed to correct it using backspace only.
- At the end of each typing session an informal chat session was held, where simple questions regarding their typing experiences were asked and responses duly noted.

The subjects were given following pangram for typing:

THE QUICK BROWN FOX JUMPS OVER A LAZY DOG.

They were expected to type it using VK both error free and complete with the full-stop. The purpose of using pangrams was that it will cover all the 26 alphabets of English ensuring that the user visits each character at least once.

IV. RESULTS AND DISCUSSIONS

The results of the user trials on seven subjects are detailed in Table IV. These experimental results show that far more errors were committed when the scan time was at 2100ms, the rotation speed being the slowest giving ample amount of time to user to make correct selection. This was contrary to the general perception that slower speed will ensure lesser error. The most probable reason, as was confirmed by the subjects in their chat sessions, was the long wait time for the pointer to rotate and move to the correct position, these long waits made them impatient and greedy resulting in errors. Also these long waits gave them ample time to start thinking about other things going on at the back of their mind, leading to frequent lapse of concentration resulting in high error rates.

When the scan period was set as 1800ms, the total number of errors committed were least but only one person could do a perfect error free typing. In the chat sessions the subjects told that though the wait time reduced yet the wait was long enough to create distractions. Also as they use the VK over a period of time, they would prefer a lower scan period (faster speed).

At the 1500ms scan period, three subjects were able to do a flawless typing. The total errors committed were high because of aberrant behavior of subject S5 who committed as many as 5 errors. During the chat session the subject S5 said these errors were totally because of his lapse of concentration as he was busy thinking about some pressing matter. Subjects S1 and S4 felt that the scan period was fast but comfortable and they may like to go faster. None of them felt that this speed of rotation was too fast or too pressing for them.

At the scan period of 1200ms, as high as 3 subjects did a flawless typing and still fewer errors were committed. Subjects S1, S2, S6 and S7 said that it was bit fast and was pressing on them, while S3 and S4 were comfortable while S5 said, he could go still faster. The general opinion was that a scan period between 1500ms and 1200ms was probably most suitable.

When the subjects were asked about the design and layout they said initially it took them a moment to memorize but then they felt very comfortable. Subject S1 said that he liked the layout because he felt that it greatly reduced the waiting time. Others held similar view and said that after a prolonged usage the scan period can be reduced considerably and may even reduce the need to view keyboard all the time. Another valuable deduction from the user trials was that when the user made WSCS error, the intended circle to be selected was mostly the sub circle immediately preceding or succeeding wrongly selected sub circle. Hence when the GO BACK element is selected in such case, instead of starting the pointer from the first sub circle, it should start from immediate predecessor sub circle.

To the question that whether they would like to suggest this VK to any person whom they know and who requires means of augmentative communication, they all replied in affirmative.

V. CONCLUSION

The virtual keyboard with multi modal access presented in this paper is an attempt to provide augmentative means of communication to people suffering for neuromuscular disorder, who have limited motor control constraining their ability to use an ordinary keyboard or other input devices like a mouse. The VK developed has multiple modes of access, hence people suffering from different levels of disability may be able to use one or more of the access methods such as the Eye tracker, or the BCI or some limited muscular activity.

The evaluation of the layout design of the proposed VK clearly establishes the superior performance measured in terms of average per character activity required for composing text. The user trials were of particular importance, although they were carried on healthy volunteers using a soft switch only. The user trials not only helped prove the robustness of the VK but also helped in performance evaluation of the layout. The various scan periods were also evaluated and an attempt was made to determine the most suitable scan times.

Although an attempt was made to cover most of the possible aspects, but still a lot of scope is left for further improvement. The user trials with the actual intended users making use of all three modalities is an utmost requirement. Also a comparative study with other existing VK like the flat VK will help in better evaluation of design. Work is also ongoing to combine BCI and eye-tracker modalities together to create a hybrid modality and evaluate its performance.

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TABLE IV RESULT OF USER TRIALS. THE TOTAL TIME IS THE TIME TAKEN INCLUDING THE TIME FROM THE MOMENT THE START TEST BUTTON IS PRESSED TILL THE TIME FINISH TEST BUTTON IS PRESSED. THIS INCLUDES THE LATENCY DELAYS AND PROCESSING TIME.

Subject	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
Scan time 2100ms							
Wrong Sub Circle	0	0	0	0	1	0	0
Wrong Character	1	5	0	0	2	2	0
Failed Selection	0	6	1	0	1	1	0
Total Errors	1	11	1	0	4	3	0
Total Time Taken (min:s)	10:38	14:58	10:19	10:04	12:14	11:36	10:04
Scan time 1800ms							
Wrong Sub Circle	0	0	1	0	0	0	0
Wrong Character	1	0	0	1	0	0	0
Failed Selection	0	2	0	0	0	1	1
Total Errors	1	2	1	1	0	1	1
Total Time Taken (min:s)	09:18	09:51	08:57	09:15	08:49	08:58	09:04
Scan time 1500ms							
Wrong Sub Circle	0	4	0	1	5	0	1
Wrong Character	1	0	0	1	0	0	0
Failed Selection	0	0	0	0	0	0	0
Total Errors	1	4	0	2	5	0	0
Total Time Taken (min:s)	07:48	07:56	07:22	8:08	09:53	07:22	07:47
Scan time 1200ms							
Wrong Sub Circle	0	1	0	1	0	0	0
Wrong Character	0	1	0	1	1	0	0
Failed Selection	2	2	0	0	0	0	0
Total Errors	2	4	0	2	1	0	0
Total Time Taken (min:s)	06:30	07:48	06:01	06:39	06:25	06:02	06:08